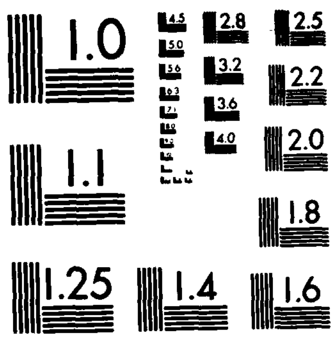
AD-A174 715 ANALYTICAL INVESTIGATIONS OF BULK WAVE RESONATORS IN THE PIEZOELECTRIC TH (U) RENSSELAER POLYTECHNIC INST TROY NY DEPT OF MECHANICAL ENGINE H F TIERSTEN 1/1

UNCLASSIFIED 30 SEP 86 AFOSR-TR-86-2035 AFOSR-84-0351 F/G 20/12 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(2)

AFOSR-TR- 86-2035

AD-A174 715

Annual Report on Analytical Investigations of Bulk Wave Resonators in the Piezoelectric Thin Film on Gallium-Arsenide Configuration

Harry F. Tiersten

86 12 04 017

September 1986

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION
Unclassified

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE

3. DISTRIBUTION/AVAILABILITY OF REPORT
Approved for public release; distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S)

5. MONITORING ORGANIZATION REPORT NUMBER(S)
AFOSR-TR- 86-2035

6a. NAME OF PERFORMING ORGANIZATION
Rensselaer Polytechnic Institute

6b. OFFICE SYMBOL *(If applicable)*

7a. NAME OF MONITORING ORGANIZATION
Air Force Office of Scientific Research

6c. ADDRESS *(City, State and ZIP Code)*
Department of Mechanical Engineering
Aeronautical Engineering & Mechanics
Troy, NY 12180-3590

7b. ADDRESS *(City, State and ZIP Code)*
Bolling Air Force Base
Bldg. 410

8a. NAME OF FUNDING/SPONSORING ORGANIZATION
Air Force Office of Scientific Research

8b. OFFICE SYMBOL *(If applicable)*
NE

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
~~Grant No~~. AFOSR-84-0351

8c. ADDRESS *(City, State and ZIP Code)*
Bolling Air Force Base
Bldg. 410

10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
61102F	2306	B2	

11. TITLE *(Include Security Classification)*
(over)

12. PERSONAL AUTHOR(S)
Harry F. Tiersten

13a. TYPE OF REPORT
Annual

13b. TIME COVERED
FROM 9/1/85 TO 8/31/86

14. DATE OF REPORT *(Yr., Mo., Day)*
1986, September 30

15. PAGE COUNT
8

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB. GR.

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
Piezoelectricity; Elasticity; Resonators; Bulk Waves; Thin Films; Semiconductor Wafers; Composite Resonators; Energy Trapping; Radiation; Quality Factor; Plate Vibrations; (over)

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

The results of earlier calculations of the quality factor of the piezoelectric thin film on semiconductor composite resonator due to radiation into the semiconductor wafer for the strip case both when trapping is and is not present are briefly discussed. Experimental verification of the results is noted. It is also noted that the direct calculation procedure is extremely cumbersome to use, but that it is required to check the accuracy of a perturbation procedure which is much easier to use. The perturbation procedure for the calculation of the quality factor of the composite resonator due to radiation into the semiconductor wafer is discussed and it is noted that the perturbation procedure enables calculations for the case of rectangular electrodes and diaphragms to be performed. It is further noted that for the strip case the calculations of the quality factor using the perturbation procedure are in good agreement with the results obtained from the earlier more cumbersome direct procedure.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT
UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS ☐

21. ABSTRACT SECURITY CLASSIFICATION
Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL
Kevin J. Malloy

22b. TELEPHONE NUMBER *(Include Area Code)*
(202) 767-4931

22c. OFFICE SYMBOL
NE

DD FORM 1473, 83 APR

EDITION OF 1 JAN 73 IS OBSOLETE.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

11. Analytical Investigations of Bulk Wave Resonators in the Piezoelectric Thin Film on Gallium-Arsenide Configuration

18. Perturbation Procedure; Rectangular Electrodes; Rectangular Diaphragms; Thickness Extensional Vibrations; Gallium-Arsenide; Aluminum-Nitride

In the previous annual report a description of the composite resonator was provided and it was noted that the values of the material constants of aluminum-nitride was open to some question. in addition, an explanation of the meaning of the words "energy trapping" was presented and the importance of its existence in high Q composite resonators was noted. It was also pointed out that the fundamental essentially thickness-extensional mode will never trap for an aluminum-nitride film on a flat gallium-arsenide plate, but that the second mode will trap for the same composite flat plate for any ratio of film-thickness to diaphragm-thickness, This was subsequently verified experimentally at Westinghouse Defense and Electronics Center.

In the previous report a somewhat detailed discussion of an analysis of the composite resonator driven by a voltage applied across strip electrodes and including radiation into the bulk semiconductor was given. In short, the calculations based on that analysis showed that when trapping is not present the Q is a very rapidly varying function of the ratio of the composite resonator thickness to the wafer thickness and that the range of variation is very large, but that when trapping is present the Q is always much larger and its range of variation much smaller than when trapping is not present. This relative stability and instability in Q when trapping is and is not present is what was observed at Westinghouse. A brief paper based on this work has been published[1] and a more comprehensive paper detailing the same work will be published[2] in October. This type of calculation is extremely cumbersome to perform and is preliminary to constructing a perturbation theory to calculate the Q due to radiation into the bulk semiconductor, which is much easier to use. The more cumbersome direct calculation is required in order to check the accuracy of the perturbation calculation.

Currently, a perturbation analysis of the Q due to radiation into the

semiconductor wafer is being performed. This analysis is considerably less cumbersome to use than the earlier direct variational treatment[1,2] and is not restricted to the case of strip electrodes and diaphragms. In the treatment the resonant mode of interest is determined from the equation for transversely varying essentially thickness-extensional modes in composite resonators[3] and simple approximate but very accurate conditions at the edge of the diaphragm. This resonant mode is then used to determine the radiation into the semiconductor wafer by means of a variational approximation procedure. Then the resonant mode and the radiation field are employed in a perturbation integral to calculate the Q. In this work only the configuration in which the film continues to the edges of the etched diaphragm is considered both when trapping is and is not present. However, now, of course, the cases of rectangular electrodes and diaphragms are being considered.

Of course, as in the earlier work[1,2], all radiating plate waves in the thick region of the gallium-arsenide must be included to achieve accuracy. Calculations utilizing the perturbation procedure have been performed for the case of strip electrodes for the same definitive geometries considered in the earlier work[1,2]. These geometries consist of wafer thicknesses ranging from 4 mils to 8 mils and a film thickness of 7 microns and diaphragm thickness of 14 microns. Although different lateral dimensions were considered in this work, for the strip case for comparison with the earlier work a diaphragm width of 500 microns was used when trapping is not present and 600, when trapping is present. The calculated results for the strip case are in good agreement with the earlier more cumbersome direct calculations[1,2]. When trapping is not present the highest Q's calculated are very nearly the same as those obtained in the earlier direct calculation[1,2], but the lowest Q's calculated by means of

the perturbation procedure tend to be nearly an order of magnitude higher than those calculated by the earlier direct procedure[1,2]. We are not absolutely sure of the reason for this discrepancy, but there are two possibilities. The perturbation procedure might be tending to lose its accuracy for low Q because of the increased radiation or the resonant frequency might not have been sufficiently precisely determined by means of the earlier direct procedure[1,2] for the accurate determination of the lowest Q values. The location of the peaks and valleys of Q with wafer thickness determined by means of the perturbation procedure is in quite good agreement with those obtained from the earlier direct calculation. When trapping is present the Q's calculated by means of the perturbation procedure are in very good agreement with those obtained from the earlier treatment. For the case of rectangular electrodes and diaphragms, the analysis has been completed and the programs have been written, but no results are as yet available.

References

1. D. S. Steven, H. F. Tiersten and D. V. Shick, "On the Reduction in Quality Factor of the Piezoelectric Thin Film on Semiconductor Composite Resonator Due to Radiation into the Bulk Semiconductor," 1985 Ultrasonics Symposium Proceedings, IEEE Cat. No. 85 CH2209-5, Institute of Electrical and Electronics Engineers, New York (1985), p. 311.

2. D. V. Shick, D. S. Stevens and H. F. Tiersten, "Quality Factor of the Piezoelectric Thin Film on Semiconductor Composite Resonator Resulting from Radiation into the Semiconductor Wafer," to be published in the Journal of Applied Physics (October, 1986).

3 H. F. Tiersten and D. S. Stevens, "An Analysis of Thickness-Extensional Trapped Energy Resonant Device Structures with Rectangular Electrodes in the Piezoelectric Thin Film on Silicon Configuration," J. Appl. Phys. 54, 5893 (1983).

A talk entitled "A Perturbation Calculation of the Quality Factor of the Piezoelectric Thin Film on Semiconductor Composite Resonator Due to Radiation into the Wafer" by D. V. Shick and H. F. Tiersten is to be presented at the upcoming 1986 Ultrasonics Symposium in mid-November. A paper with the same title is to be published in the 1986 Ultrasonics Symposium Proceedings. The abstract of the talk is appended to this report.

Publications

"On the Reduction in Quality Factor of the Piezoelectric Thin Film on Semiconductor Composite Resonator Due to Radiation into the Bulk Semiconductor," D. S. Stevens, H. F. Tiersten and D. V. Shick, 1985 Ultrasonics Symposium Proceedings, IEEE Catalog Number 85 CH2209-5, Institute of Electrical and Electronics Engineers, New York, 311-318 (1985).

"Quality Factor of the Piezoelectric Thin Film on Semiconductor Composite Resonator Resulting from Radiation into the Semiconductor Wafer," D. V. Shick, D. S. Stevens and H. F. Tiersten, to be published in the Journal of Applied Physics (October, 1986).

A PERTURBATION CALCULATION OF THE QUALITY FACTOR OF THE PIEZOELECTRIC THIN FILM ON SEMICONDUCTOR COMPOSITE RESONATOR DUE TO RADIATION INTO THE WAFER*

D. V. Shick and H. F. Tiersten, Rensselaer Polytechnic Institute,
Troy, NY 12180-3590.

In a recent analysis of the piezoelectric thin film on semiconductor composite resonator vibrating in an essentially thickness-extensional mode it was shown that the quality factor (Q) due to radiation into the bulk semiconductor is a very sharply varying function of the ratio of the thickness of the resonator to that of the film if trapping is not present, but not if trapping is present. The treatment employs a very accurate but extremely cumbersome variational approximation technique and is restricted to the case of strip electrodes and diaphragms. In this work a perturbation analysis of the Q due to radiation into the semiconductor wafer is presented, which is considerably less cumbersome to use than the earlier variational treatment and is not restricted to the case of strip electrodes and diaphragms. In the treatment the resonant mode of interest is determined from the equation for transversely varying essentially thickness-extensional modes in composite resonators and simple approximate but very accurate conditions at the edge of the diaphragm, from which the radiation into the wafer is determined by means of a variational approximation procedure. Then the resonant mode and the radiation field are employed in a perturbation integral to calculate the Q. For the case of strip electrodes and diaphragms the calculated results are shown to be in good agreement with the earlier more cumbersome calculations. In addition, it is shown that the perturbation calculations are readily performed for the case of rectangular electrodes and diaphragms.

*This work was supported in part by AFOSR under Grant No. AFOSR-84-0351.

H. F. Tiersten
Department of Mechanical Engineering,
Aeronautical Engineering & Mechanics
Rensselaer Polytechnic Institute
Troy, NY 12180-3590

END

1-87

DTIC